HISTORICAL AND LATE-CENTURY RAINFALL SEASONALITY OVER PARTS OF THE HADEJIA-JAMA'ARE RIVER BASIN

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ABSTRACT

Rainfall seasonality in Nigeria is expected to be subjected to some alteration due to climate change, with some adverse consequences for water resources and the agro-hydrological system.

Due to the dearth of knowledge about future changes in rainfall regime, this study analysed the relative seasonality of rainfall for the historical (1971-2000) and late-century (2071-2100) periods over the Hadejia-Jama'are River Basin using Walsh and Lawler's rainfall seasonality index. The trends in the time series of the seasonality indices were examined using the Mann-Kendall trend test. The rainfall seasonality index showed that the rainfall regime during the late century will remain generally seasonal, similar to the regime for the historical period, with indices in the range of 0.60 to 0.79. The Mann-Kendall trend test indicated no significant changes in the rainfall regime of the study period. The results indicate among others, that there are likely to be minimal changes in local convective activities during the late-century.

Keywords: Climate model, Future rainfall, Northern Nigeria, River, Seasonality index

INTRODUCTION

Annual rainfall over Northern Nigeria occurs largely during the wet season, between May and October in the midland zone and between June and September in the Sahel Zone (Olaniran & Sumner 1989). On the average, annual rainfall in the region varies between 879 mm and 1535 mm (Gbode et al., (2019). Despite the significant contribution of the wet season rainfall to the total annual rainfall, rainfall is highly variable, with variability as high as 30 percent occurring in the North-Eastern part of Nigeria (Oguntunde et al., 2011). Such levels of rainfall variability have implications for the predominantly rain-fed farming systems of the region, the management of water resources, especially hydraulic structures such as dams and irrigation facilities, as well as the functioning of vulnerable ecosystems such as wetlands. Due to the semi-arid climatic conditions and the high dependence of the region's agriculture on rainfall, an in-depth understanding of the seasonality of rainfall in the future is of great importance to the socio-economic well-being of the people in the region. Rainfall seasonality described as the seasonal contrasts in rainfall amounts (Livada & Asimakopolus, 2005) depends on the timing or duration of the rainy season, and changes in seasonality could have significant implications for decision-making in agricultural scheduling and sustainable management of water resources.

Walsh and Lawler (1981), described 5 aspects of rainfall regimes, namely, absolute seasonality, relative seasonality, number of rainfall maxima and minima, timing of rainfall maxima and minima, and variability and distribution of rainfall distribution from year to year. The relative seasonality index which was used to assess the seasonal contrasts in rainfall amount throughout the year for selected locations, most of which are in the tropics showed considerable differences in the relative seasonality of the locations.

Livada and Asimakopolus (2005) employed the relative seasonality index to assess the seasonality of rainfall in different geographical regions of Greece and found that the rainfall regime varied between 'rather seasonal with a short drier season' and 'most rain in three months or less'. The analyses of precipitation seasonality in the eastern and southern coast of Spain by Sumner et al. (2001) revealed that precipitation was increasingly seasonal in the southern coast during the period 1964 and 1993.

In a study by Odekunle and Adejuwon (2007), the results of the analyses of rainfall seasonality over Nigeria between 1961 and 2004, revealed that the rainfall regime in the northern part of the country fell within the category of " most rainfall in three months or less" while rainfall in the southern parts were rather seasonal with a shorter drier season. In another study by Gbangou et al. (2018), rainfall seasonality for the present-day climate at Awun river basin in Ilorin, Nigeria, was categorised as being seasonal while future seasonality of rainfall was projected to be markedly seasonal with longer drier season under two contrasting emission scenarios.

In a study to re-classify the agro-climatic zones of Ghana based on the current reality of climatic change and variability, Yamba et al. (2023) used the rainfall seasonality index to assess the seasonality of rainfall for 3 climatic periods, 1921 to 1950, 1951 to 1980, and 1981 to 2010. The results of the study showed amongst others that the highest values of rainfall seasonality index which signifies drier conditions were observed over the northern parts of the country and also that the values of the rainfall seasonality index generally increased from one climatic period to another.

Given that some studies have assessed the seasonality of rainfall in some parts of Nigeria for the historical period, only few studies have analysed the expected future rainfall seasonality in different parts of Nigeria, especially in the northern parts where rainfall is highly seasonal. This study therefore aims to assess the projected rainfall seasonality over Hadejia-Jama'are River Basin, which is a very important river catchment in northern Nigeria, using a selected Regional Climate Model (RCM) from the Coordinated Regional Climate Downscaling Experiment (CORDEX).

THE STUDY AREA

The Hadejia-Jama'are River Basin (HJRB) is a sub-basin of the Komadugu-Yobe River Basin, located in the semi-arid region of northern Nigeria (Goes, 2001; Odunuga et al., 2011). The basin lies approximately between Latitudes 10°N and 13°N and between Longitudes 8°E and 12°E. Annual rainfall in the basin is highly variable, ranging between 500 mm per annum in the north-eastern part of the basin to 1,300 mm per annum in the south-western part. Annual rainfall in the catchment is mostly concentrated in a unimodal wet season which is between May and September (Adams & Thomas, 1996).

The hydrologic regime of the Hadejia and Jama'are rivers is seasonal, similar to the rainfall regime. About 80 percent of the total runoff of the two rivers occurs in the months of August and September (Adams & Thomas, 1996). A number of hydraulic and water management facilities are located within the basin; These include the Tiga Dam which was built on River Kano, a tributary of River Hadejia, between 1971 and 1974 (Thomas & Adams, 1997) and Challawa Gorge Dam which was constructed on Challawa River in 1992 (World Bank / Lake Chad Basin Commission, 2002). Apart from the dams, other structures located within the basin are the Kano

River Irrigation Project and Hadejia Valley Irrigation Project (Barbier, 2003). Figure 1 shows the Hadejia-Jama’are River Basin.

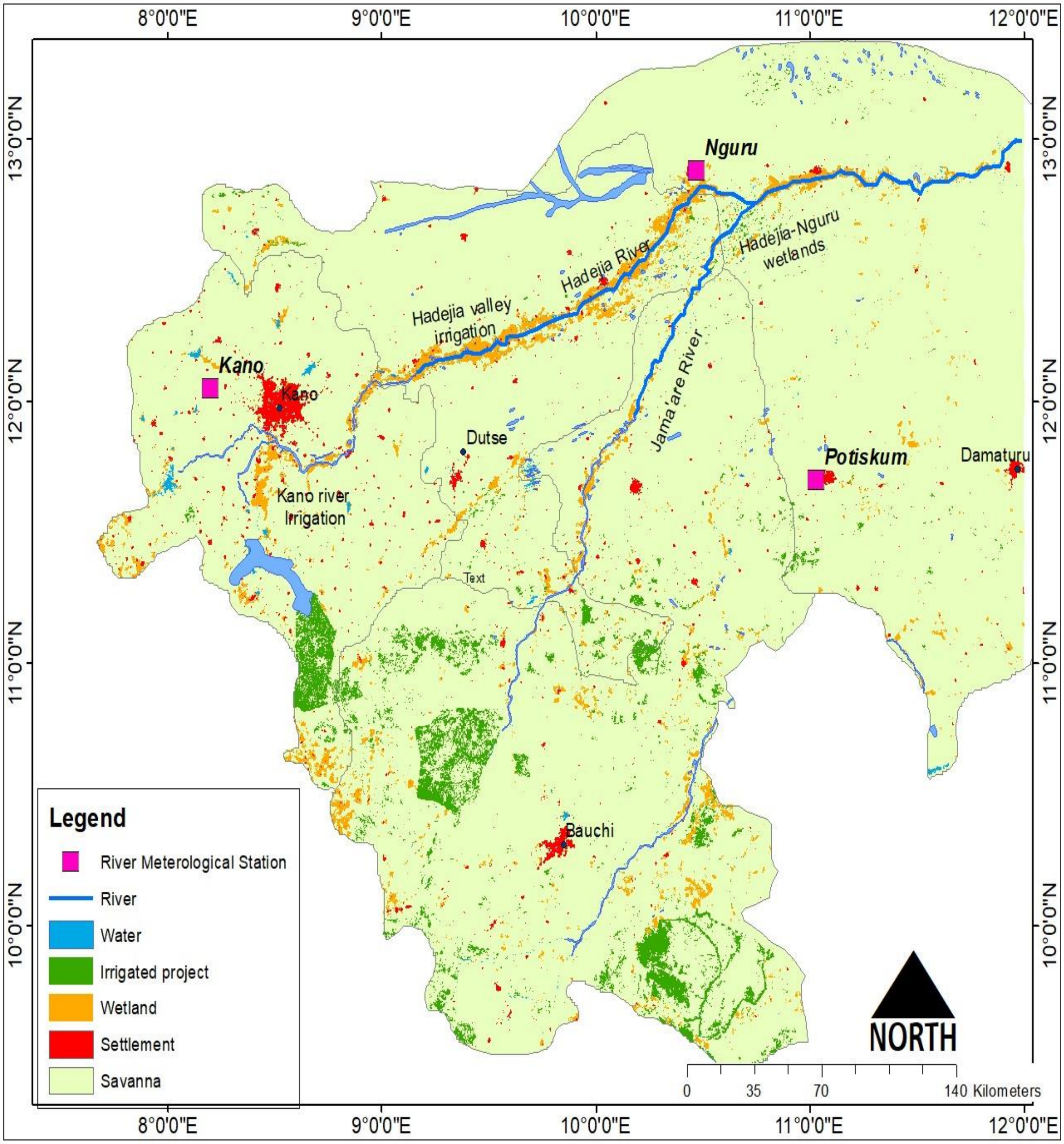

Figure 1: The Hadejia-Jama’are River Basin

MATERIALS AND METHODS

Dataset

Daily rainfall projections from MPI-M-MPI-ESM-LR (Max Planck Institute for Meteorology, Earth System Model, Low Resolution), one of the models driven by the Coupled Model Inter-comparison Project Phase 5 (CMIP5) Global Climate Models downscaled by the Rosby Centre Regional Climate Model (RCA4) was utilised for this study. The RCA4 was developed by Svergies Meteorological och Hydrologiska Intitut (SMHI), Sweden, under CORDEX Africa and is available at https://esg-dn1.nsc.liu.se/search/cordex/.

A single ensemble (r1i1p1) for two Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the late century (2071-2100) was employed for this study. MPI-M-MPI-ESM-LR was used because some studies, for example, Kebe et al., (2016) and Heinzeller et al., (2018) have shown that the model performs well in representing the rainfall features of the West African monsoon. RCP 4.5 and 8.5 which represent slowly declining and rising emissions respectively were selected for comparison and to ascertain if marked differences are expected in the future rainfall seasonality under an intermediate and high greenhouse gas emission in the study area.

Daily rainfall data obtained from MPI-M-MPI-ESM-LR and observational data from three selected meteorological stations (Table 1) obtained from the archives of the Nigerian Meteorological Agency (NIMET) were used to analyse the rainfall seasonality for the baseline period of 1971-2000. These data are maintained following the World Meteorological Organisation (WMO) approved guidelines and quality control. The daily rainfall data that were used were all aggregated to monthly data for the purpose of analysis.

Table 1: Details of Selected Meteorological Stations

Station	WMO ID	Longitude (^{0}N)	Latitude (^{0}E)	Elevation (m)
Kano	65046	12.05	8.20	472.5
Nguru	65064	12.88	10.47	343.1
Potiskum	65073	11.70	11.03	414.8

Data Analysis

Rainfall Seasonality

The relative seasonality of rainfall for the baseline period (for both observed and model data) and the late century was assessed using the Seasonality Index (SI) developed by Walsh and Lawler (1981). The SI which is defined as the sum of absolute deviation of mean monthly rainfall from overall monthly mean divided by the mean annual rainfall is expressed as:

$$SI = \frac{1}{\bar{R}}\sum_{n=1}^{n=12} \bar{X}_n - \frac{\bar{R}}{12} \qquad (1)$$

Where X_n = mean rainfall of month n; and $\bar{R}$ = mean annual rainfall
The categorisation of the degree of seasonality based on the index is as presented in Table 2.

Table 2: Categorisation of the degree of seasonality based on the Seasonality Index

Rainfall Regime	SI Class Limits
Very equable	≤ 0.19
Equable but with a definite wetter season	0.20 – 0.39
Rather seasonal with a shorter drier season	0.40 – 0.59
Seasonal	0.60 – 0.79
Markedly seasonal with long drier season	0.80 – 0.99
Most rain in 3 months or less	1.00 – 1.19
Extreme, almost all rain in one or two months	≥ 1.20

Source: Walsh and Lawler (1981)

Trend in Rainfall Seasonality

The non-parametric Mann-Kendall trend test was used to test for the presence of trends in the time series of the SI index. The Mann-Kendall trend test is expressed as:

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \qquad (2)$$

A positive S value indicates an increasing trend a negative value indicates a decreasing trend in the data time series. The sign function is expressed as:

$$Sgn\left(X_j - X_i\right) = \begin{cases} 1 \; if \; X_j - X_i > 0 \\ 0 \; if \; X_j - X_i = 0 \\ -1 \; if \; X_j - X_i < 0 \end{cases} \qquad (3)$$

Where the sample size n > 10, the statistics S is approximately standard normal distribution with a mean that equals 0 and a variance denoted by:

$$VAR\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\,(t_i-1)(2t_i+5)}{18} \qquad (4)$$

Where n is the number of data points, t_j are the ties of the sample time series, and m is the number of tied values. The test statistic, Z is given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR}(S)} \; if \; S > 0 \\ 0 \qquad if \; S = 0 \\ \frac{S+1}{\sqrt{VAR}(S)} \; if \; S < 0 \end{cases} \qquad (5)$$

The Z-statistic was used to test the null hypothesis (H_0) that there is no trend, against the alternative hypothesis (H_1) that there is trend. In order to estimate the actual slope of a trend, the Sen's slope estimator expressed in equation 6, was used (Lamboni et al., 2019; Adeyeri et al., 2019, Animashaun et al., 2020)

$$\beta = Median(\frac{x_j - x_k}{j-k}) \qquad (6)$$

Evaluation of Accuracy

In order to test the degree of linear relationship between the SI derived from the observed and model data for the baseline period, the Coefficient of Determination (R^2) (equation 7) was used.

$$R^2 = \left[\frac{\sum_{i=1}^{n} (y_i - \bar{y}\ )\ (o_i - \bar{o})}{\sqrt{[\sum_{i=1}^{n} (y_i - \bar{y})^2)\ (\sum_{i=1}^{n} (o_i - \bar{o}\ )^2)]}}\right] \qquad (7)$$

Where y and o are the predicted and observed annual values in the time series, and $\bar{y}$ and $\bar{o}$ are mean of the predicted and observed time series respectively.

RESULTS AND DISCUSSION

Rainfall Seasonality Indices and Trend

The results of the seasonality indices for the baseline period for both observational and model data show that the rainfall regime between 1971 and 2000 was predominantly seasonal, varying between 0.60 and 0.79. The mean seasonality indices for most of the locations was 0.61. With regards to the observational data, the exception to the general seasonal regime of rainfall of the basin was the "rather seasonal with a shorter drier season regime'' associated with the rainfall regime of 1978, 1988, 1997, and 1998 at Kano, the 1974 rainfall regime at Nguru and the rainfall regime for 1981, and 1989 at Potiskum. For the model data, the "rather seasonal with a shorter drier season regime'' is associated with rainfall regime of 1973, 1976, 1985, 1988, 1989, and 1998 at Kano, the rainfall regime of 1975, 1984, 1996, 1997 and 1998 at Nguru, and the rainfall regime of 1971, 1984, 1991, 1994, and 1997 at Potiskum.

For the late century, the rainfall regime for both RCP 4.5 and RCP 8.5 are projected to be mostly seasonal. Under RCP 4.5, the exception to the predominantly seasonal rainfall regime, fall within the "rather seasonal with a shorter drier season regime'' projected for the rainfall regime of 2072, 2078 and 2092 at Kano, the "rather seasonal with a shorter drier season regime'' and the equable but with definite wetter season" projected for 2073 and 2080 respectively for Nguru, and the "rather seasonal with a shorter drier season regime'' projected for 2082, 2088, 2090, 2091, 2099, and 2100 at Potiskum. Under RCP 8.5, the "rather seasonal with a shorter drier season regime'' are expected in 2071, 2075, 2082, 2086, and 2094 at Kano, in the year 2080 at Nguru, and 2076, 2079, 2084, 2089, and 2094 at Potiskum.

The "rather seasonal with shorter drier regime" could be an indication of wetter conditions, which could range from mild to moderate wetness, enhancing water availability and reducing the dependence on supplemental irrigation. The seasonality indices for the observational and model data for the baseline period are as shown in Figures 2 to 7, while the seasonality indices of the late century under RCP 4.5 and 8.5 are as shown in Figures 8 to 13. Similarly, the mean seasonality indices for both the baseline and the late century are as shown in Table 3.

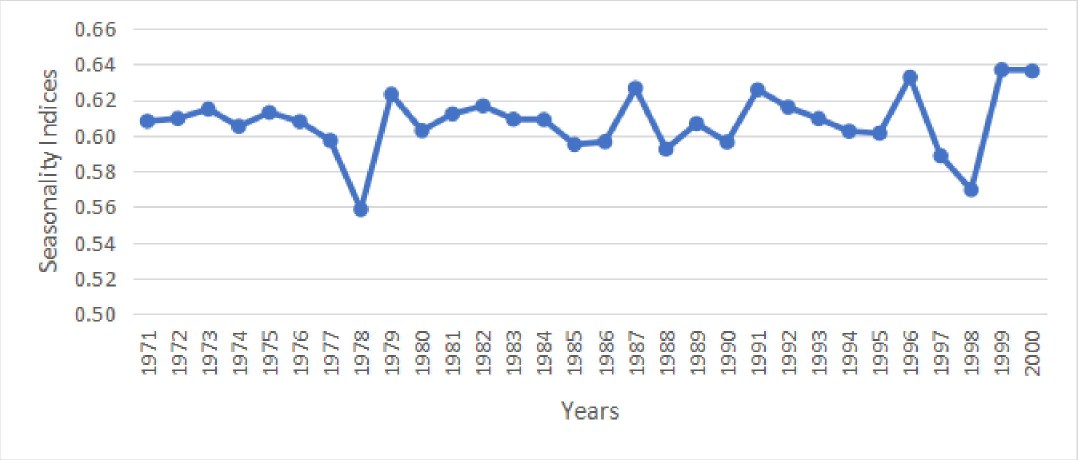

Figure 2: Seasonality of rainfall for Kano from the baseline period based on observed data

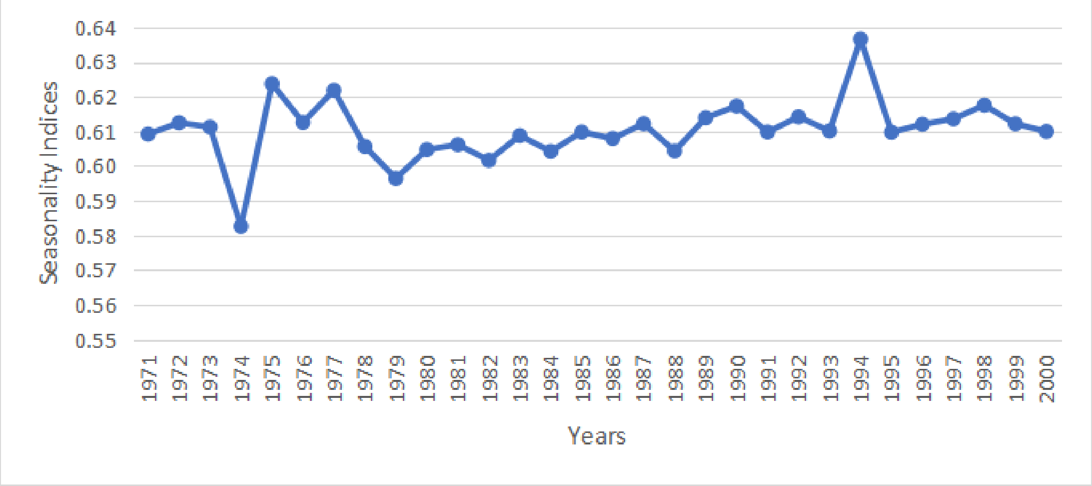

Figure 3: Seasonality of rainfall for Nguru from the baseline period based on observed data

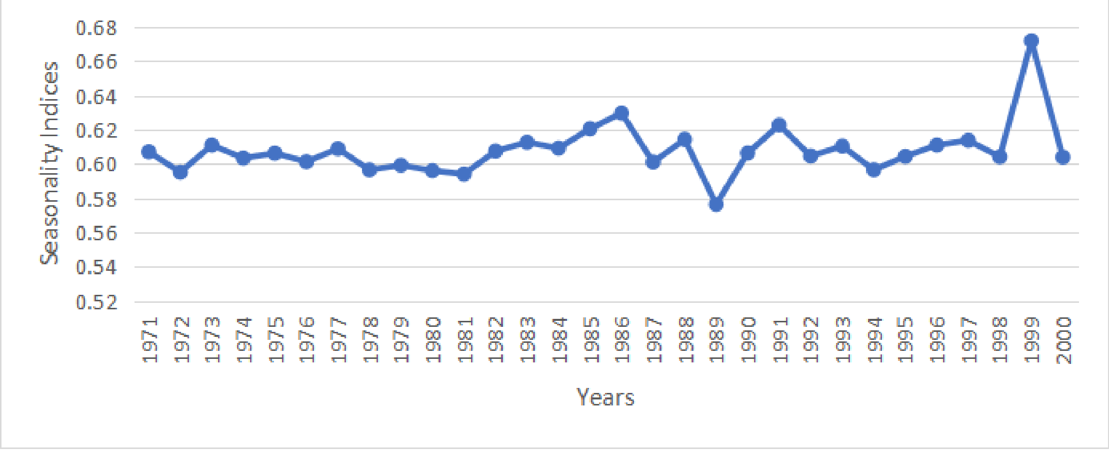

Figure 4: Seasonality of rainfall for Potiskum from the baseline period based on observed data

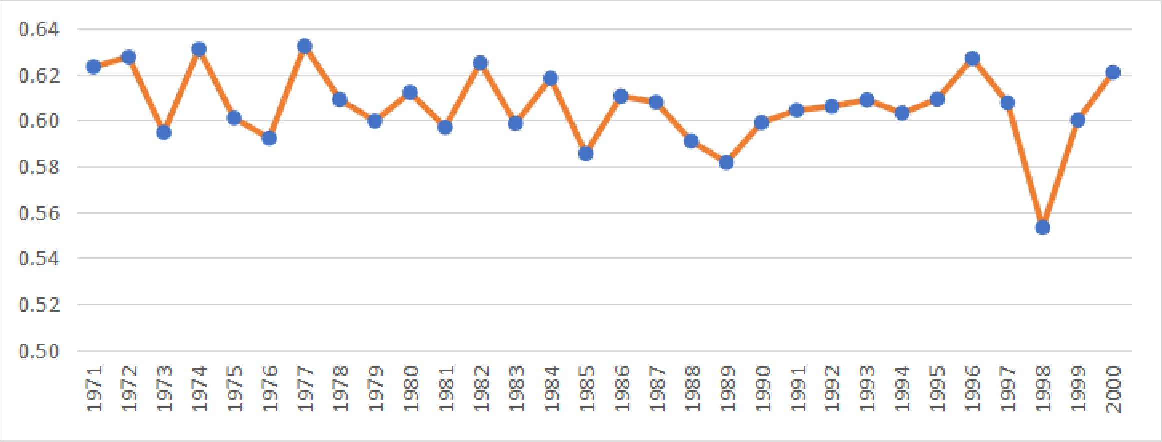

Figure 5: Seasonality of rainfall for Kano from the baseline period based on MPI-M-MPI-ESM-LR data

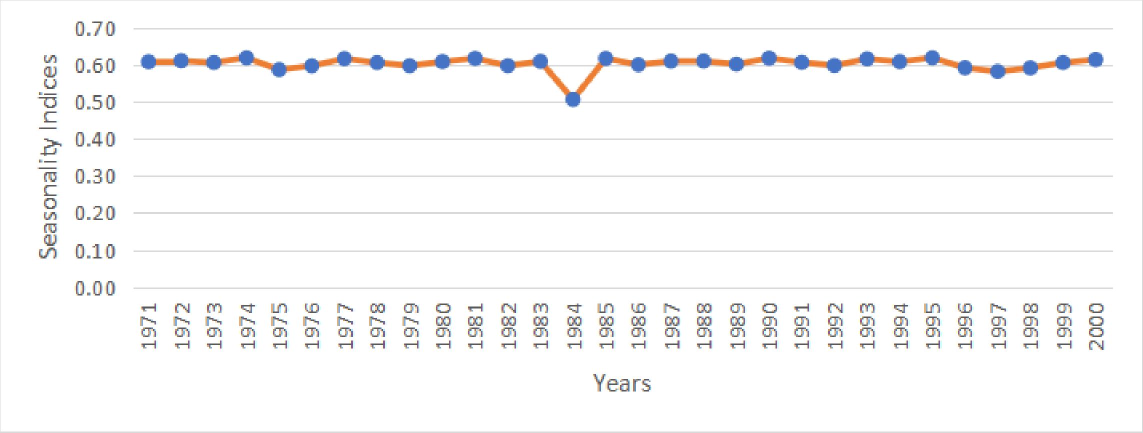

Figure 6: Seasonality of rainfall for Nguru from the baseline period based on MPI-M-MPI-ESM-LR data

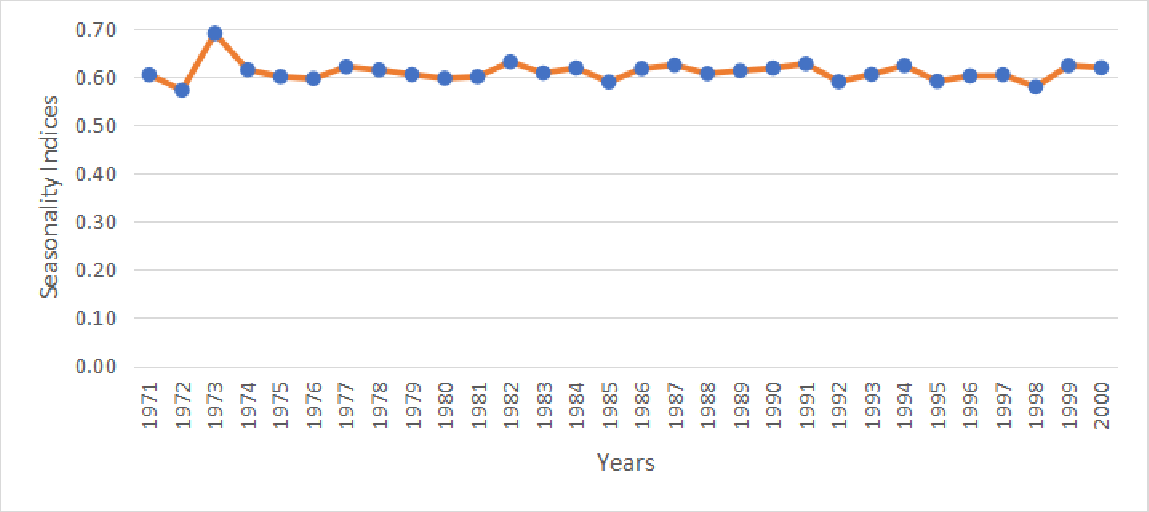

Figure 7: Seasonality of rainfall for Potiskum from the baseline period based on MPI-M-MPI-ESM-LR data

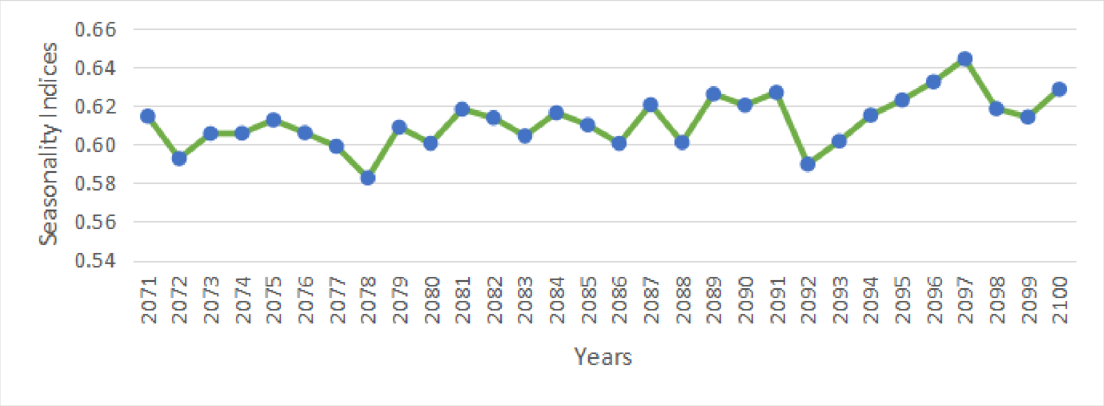

Figure 8: Seasonality of rainfall for Kano for the late century under RCP 4.5

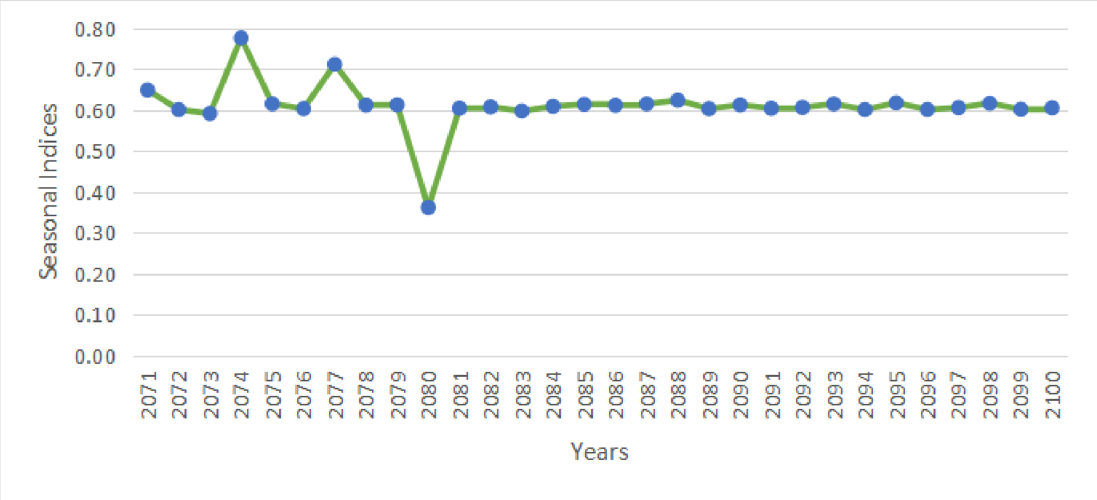

Figure 9: Seasonality of rainfall for Nguru for the late century under RCP 4.5

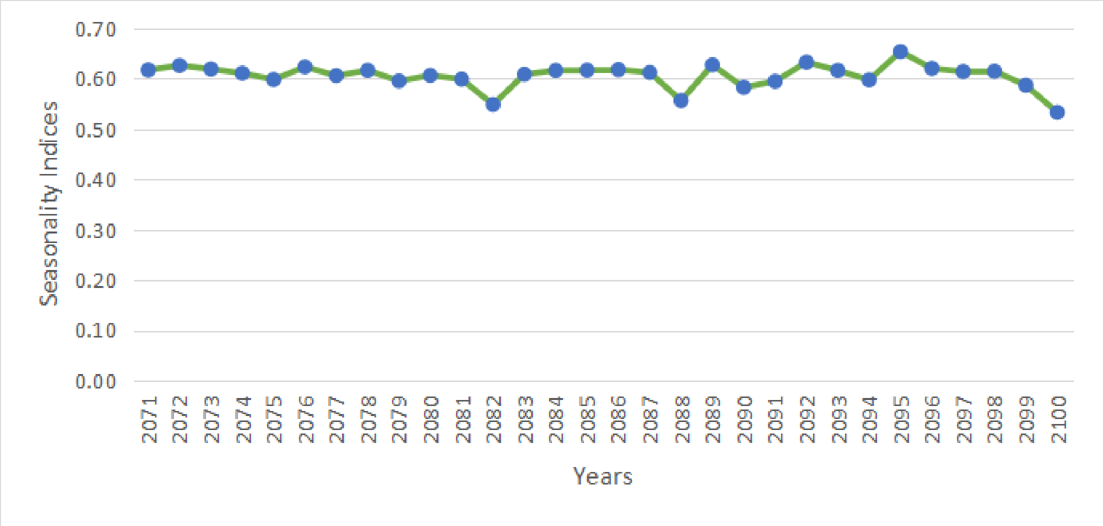

Figure 10: Seasonality of rainfall for Potiskum for the late century under RCP 4.5

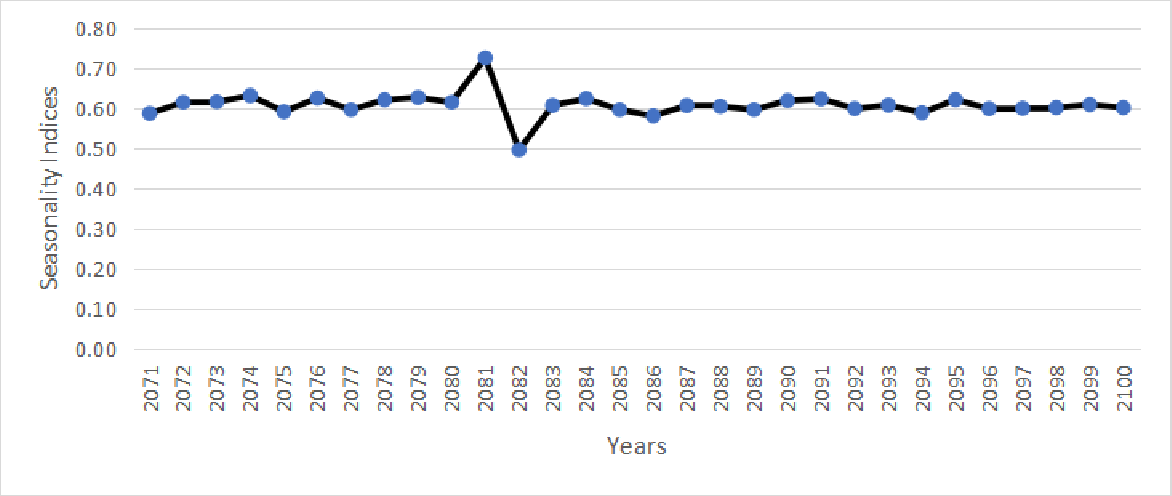

Figure 11: Seasonality of rainfall for Kano for the late century under RCP 8.5

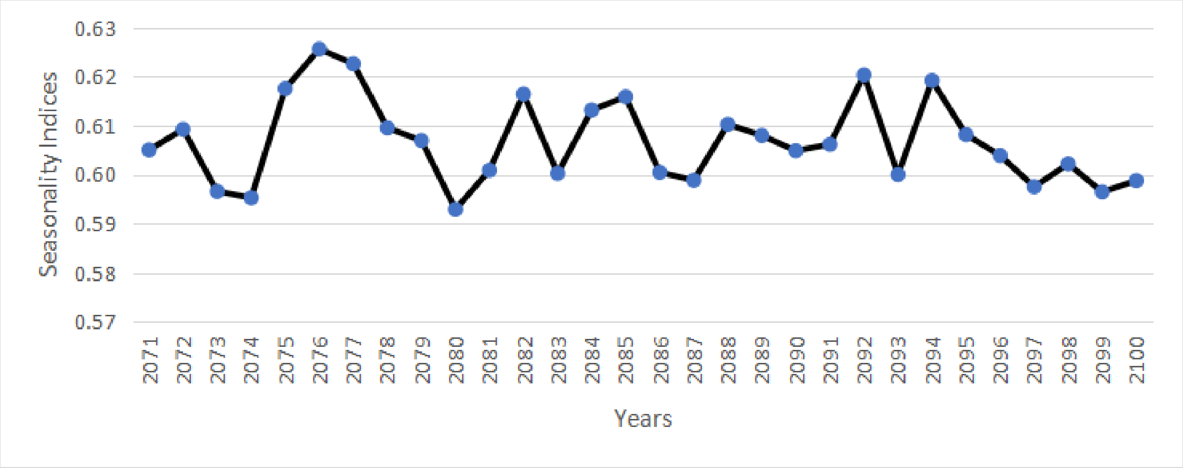

Figure 12: Seasonality of rainfall for Nguru for the late century under RCP 8.5

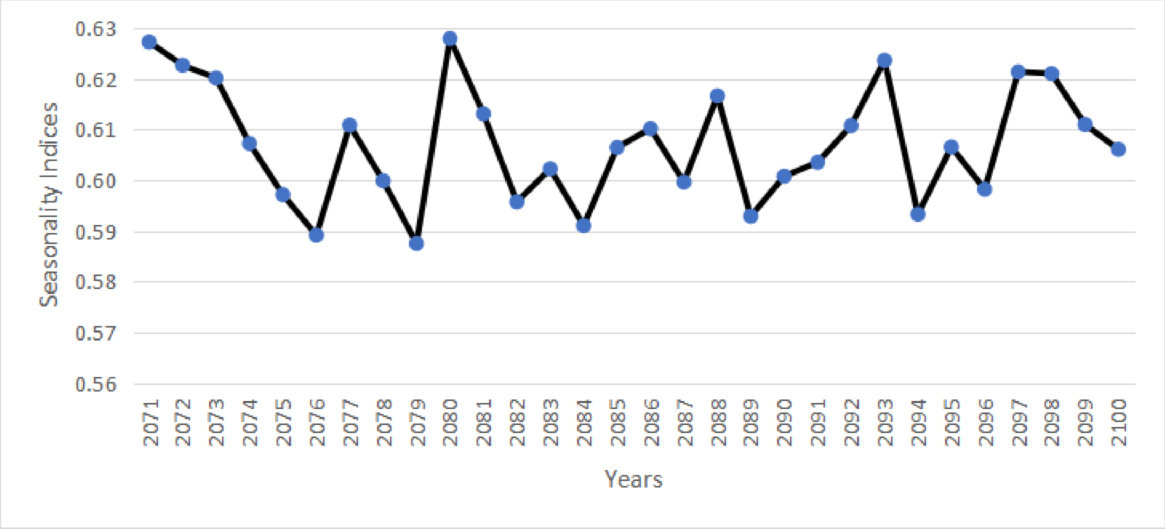

Figure 13: Seasonality of rainfall for Potiskum for the late century under RCP 8.5

Table 3: Mean seasonality indices for the baseline and late century

Station	Observed Data (1971-200)	MPI-M-MPI-ESM-LR (1971-2000)	RCP 4.5 (2071-2100)	RCP 8.5 (2071-2000)
Kano	0.61	0.61	0.61	0.61
Nguru	0.61	0.60	0.61	0.61
Potiskum	0.61	0.61	0.61	0.61

The results of the Mann-Kendall trend test (Table 4) show that the p-value is generally greater than the significance level at α = 0.05, indicating that there is no trend in the seasonality indices for both RCP 4.5 and 8.5. The only exception to this is likely to be at Nguru in the late century, under RCP 4.5, where the p-value is lower than the significance level at α = 0.05. The no trend result is an indication of no significant changes which is in line with the rainfall regime which is expected to remain predominantly the same.

Table 4: Results of the Mann-Kendall Trend Test for the Seasonality indices

Station	Baseline Period		Late Century	
	Observed Data	MPI-M-MPI-ESM-LR	RCP 4.5	RCP 8.5
Kano	τ = 0.012	τ = -0.113	τ = 0.393	τ = -0.094
	P-value = 0.944	P-value = 0.396	P-value = 0.002	P-value = 0.479
Nguru	τ = 0.012	τ = -0.113	τ = 0.393	τ = -0.094
	P-value = 0.944	P-value = 0.396	P-value = 0.002	P-value = 0.479
Potiskum	τ = 0.012	τ = -0.113	τ = 0.393	τ = -0.094
	P-value = 0.944	P-value = 0.396	P-value = 0.002	P-value = 0.479
	*Significance level α = 0.05			

Evaluation of Accuracy

Table 5 show the results of the Coefficient of Determination (R^2). As shown in the table, there is a perfect relationship between the observed and model data for the baseline period. This indicates that the model has a high ability to represent the seasonality of rainfall in the HJRB.

Table 5: Results of the Coefficient of Determination

Station	Kano	Nguru	Potiskum
SI for Observational Data	1	1	1
SI for MPI-M-MPI-ESM-LR Data	1	1	1

As observed from the results, the rainfall regime of the basin is likely to remain unchanged from the baseline period to the late 21st century. Generally, the rainfall regime at the HJRB is under the influence of certain atmospheric circulation systems that govern its inter-annual variability. These are the Inter-tropical Convergence Zone, the African Easterly Jet (AEJ), the Tropical Easterly Jet (TEJ), the African Westerly Jet (AWJ), and the Saharan Heat Low (SHL) (Nicholson, 2013).

The projected predominance of the seasonal regime for the late 21st century suggests that changes in local convective activities will be very minimal as only a few exceptions to this regime are likely to be experienced in the basin. This also suggests the likelihood of less disruption in the agricultural calendar, especially in the scheduling of planting and harvesting of crops grown in the basin. Despite the likelihood of less disruption in the agricultural calendar, changes in land cover and land use, as well as siltation of some reservoirs in the basin may affect availability of water for agriculture. Furthermore, water availability in the basin is likely to come under increasing stress due to rapid population growth and an increase in water demand. In the same vein, water allocation problems which may be occasioned by rising population and increase in water demand could further worsen the recurrent farmer-herder clashes if effective water management strategies are not implemented.

The generally seasonal regime that is projected for the basin's rainfall has the potential to sustain its overriding impact on the livelihoods of the populace, some of whom engage in flood recession agriculture. According to Oyebande (1995) and Umar et al., (2018), the historical hydrologic regime of rivers in the basin has always had a great impact on flood recession farming, implying that future agricultural practices in the basin could still be largely subjected to the seasonality of rainfall. Based on the generally seasonal rainfall regime being projected for the late century, it is recommended that less water-intensive cropping practices should be adopted for sustainable agricultural productivity and enhancement of climate resilience. It is also recommended that a robust agriculture information management strategy that takes cognizance of the potential behaviour of rainfall variability under different climate change scenarios should be incorporated into water resources planning and management at basin.

CONCLUSION

The analysis of seasonality of rainfall in the HJRB via Walsh and Lawler (1981) Seasonality Index showed a predominantly seasonal rainfall regime for both the baseline and the late century. Similarly, the results of the Mann-Kendall trend test indicated that there will be no significant changes in the seasonality indices, and hence the rainfall regime. The prediction of various aspects of the climate several years in advance is of great importance in ensuring future sustainability and limiting the uncertainty associated with the management of water resources and agriculture. At the basin level, the use of such climate information can aid decision-making and policy guidance for improving the resilience of the agricultural and water resources systems to some of the negative consequences of climate variability and change.

REFERENCES

Adams, W.M., & Thomas, D.H. (1996). Conservation and sustainable resource use in the Hadejia-Jama'are Valley, Nigeria. *Oryx,* 30(2), 131-142.

Adeyeri, O.E., Lawin, A.E., Laux, P., Ishoal, K.A., & Ige, S.O. (2019). Analysis of climate extreme indices over Komadugu-Yobe basin, Lake Chad region: past and future occurrences. *Weather and Climate Extremes,* 23, 1-24.

Animashaun, I.M., Oguntude, P.G., Akinwumiju, A.S., & Olubanjo, O.O. (2020). *Scientific African,* 8, e00419. https://doi.org/10.1016/j.sciaf.2020.e00419.

Barbier, E.B. (2003). Upstream dams and downstream water allocation: the case of the Hadejia-Jama'are floodplain, northern Nigeria. *Water Resources Research*, 39(11), 1-9.

Gbangou, T., Sylla, M.B., Jimoh, O.D., & Okhimanhe, A.A. (2018). Assessment of projected agro-climatic indices over Awum river basin, Nigeria for the late twenty-first century. *Climatic Change.* https://doi.org/10.1007/S10584-018-2295-y.

Gbode, I.M., Adeyei, O.E., Menang, K.P., Intsiful, J.DK., Ajayi, V.O., Omotosho, J.A., & Akinsanola, A.A. (2019). Observed changes in climate extremes in Nigeria. *Meteorological Applications,* 26, 642-654. DOI:10.1002/met.1791.

Goes, M.J. (2001). Effect of daming the Hadejia River in semi-arid northern Nigeria. In Regional Management of Water Resources. Proceedings of the 6th Scientific Assembly of IAHS, Maastricht, Netherlands, 18-27 July, 2011, IAHS Publ, 268, 73-80.

Heinzeller, D., Dieng, D., Smiatek, G., Olusegun, C., Klein, C., Hamann, I., Salack, S., Bliefernicht, J., & Kunstmann, H. (2018). The WASCAL high resolution regional climate simulation ensemble for West Africa: concept, dissemination and assessment. *Earth System Science Data*, 10(2), 815-835.

Kebe, L., Sylla, M.B., Omotosho, J.A., Nikiema, P.M., Gibba, P., & Giorgi, F. (2016). Impact of GCM boundary forcing on regional climate modelling of West African summer monsoon precipitation and circulation features. *Climate Dynamics*, 48, 1503 – 1516.

Lamboni, B., Emmanuel, L.A., Manira-Kiza, C., & Djibib, Z.M. (2019). Variability of future rainfall over Mono river basin of West Africa. *American Journal of Climate Change*, 8, 137-155. https://doi.org/10.4236/ajcc.2019.8.81008.

Livada, I., & Asimakopolous, D.N. (2005). Individual seasonality index of rainfall regimes in Greece. *Climate Research*, 23, 155-161.

Nicholson, S.E. (2013). The West Africa Sahel. A review of recent studies on the rainfall regime and its inter-annual variability. ISRN Meteorology, 2013, Article ID 453521. http://dx.doi.org/10.10.1155/2013/453521.

Odekunle, T.O., & Adejuwon, S.A. (2007). Assessing changes in the rainfall regime in Nigeria between 1961 and 2004. *Geojournal,* 70, 145-159. DOI 10:1007/s/10708-008-9121-4.

Oguntunde, P.G., Abiodun, B.J., & Lischeid, G. (2011). Rainfall trends in Nigeria, 1901-2000. *Journal of Hydrology*, 411, 207-218. Doi:10.1016/j.jhydrol.2011.09.037.

Odunuga, S., Okeke, I., Omojola, A., & Oyebande, L. (2011). Hydroclimatic variability of the Hadejia-Jama'are river system in north central Nigeria. In Hydro-climatology: Variability and Change. Proceedings of the symposium J-H02, Melbourne, Australia, 27 June -8 July, 2011, IAHS Press: Wallinford, UK, 344, 163-168.

Olaniran, O.J., & Sumner, G.N. (1989). A study of climatic variability in Nigeria based on the onset, retreat and length of the rainy season. *International Journal of Climatology*, 9, 253-269.

Oyebande, L. (1995). Effects of reservoir operation on the hydrological regime and water availability in Northern Nigeria. In Man's influence on Freshwater Ecosystem and Water Use. Proceedings of Boulder Symposium, July, 1995, IAHS Publ, 230, 101-112.

Thomas, D.H.L., & Adams, W.M. (1997). Space, time and sustainability in the Hadejia-Jama'are wetlands and Komadugu Yobe Basin Nigeria. *Transactions of the Institute of British Geographers*, 22(4), 430-449.

Umar, D.A., Ramli, M.F., Aris, A.Z., Jamil, N.R., & Abdulkareem, J.H. (2018). Runoff irregularities, trends, and variations in tropical semi-arid river catchment. *Journal of Hydrology: Regional Studies*, 19, 335-348. https://doi.org/10.1016/j.ejrh.2018.10.008.

Walsh, R.P.D & Lawler, D.M. (1981). Rainfall seasonality: description, spatial patterns and change through time. *Weather*, 36, 201-204.

World Bank/ Lake Chad Basin Commission (2002). Appraisal of safety of the Tiga and Challawa Gorge Dams, Nigeria. E564, Vol 2.

Yamba, E.T., Aryee, J.N.A., Quanasah, E., Davies, P., Wemegah, C.S., Osei, M.A., Ahiataku, M.A., & Amekudzi, L.K. (2023). Revisting the agro-climatic zones of Ghana: A re-classification in conformity with climate change and variability. *PLOS Climate*, 2(1):e0000023. https://fdoi.org/10.1371/journal.pclm.0000023.